Testimony of
The American Society of Civil Engineers
Before the
House Committee on Transportation and Infrastructure
on
Highway Bridge Inspections

October 23, 2007

Chairman DeFazio, Congressman Duncan and Members of the Committee:

Good afternoon. I am Glenn Washer, PhD., P.E., past chair of the Committee on Bridge Management, Inspection and Rehabilitation of the American Society of Civil Engineers (ASCE)[*], and Assistant Professor, at the University of Missouri – Columbia. I am a licensed Professional Engineer in Virginia. Previously, I have served as the director of the FHWA Nondestructive Evaluation (NDE) program at the Turner Fairbank Research Center (TFHRC). I currently teach and conduct research related to the development of nondestructive evaluation technologies. My research sponsors include the Departments of Transportation of Missouri, Texas, New York State and Tennessee, the University Transportation Center (UTC) at Rolla, the National Cooperative Highway Research Program (NCHRP) and NASA.

Let me start by thanking you for holding this hearing. As someone who has worked in this field for many years, I can say that there are few infrastructure issues of greater importance to Americans today than bridge safety, and I am pleased to discuss the role of nondestructive evaluation in the inspection process that helps ensure that safety.

I am pleased to appear today to be able to lend ASCE's expertise on the issue of bridge inspections and Nondestructive Evaluation of bridges.

I. Bridge Inspection Program

The National Bridge Inspection Standards (NBIS), in place since the early 1970s, require biennial safety inspections for bridges in excess of 20 feet in total length located on public roads. These inspections are to be performed by qualified inspectors. Structures with advanced deterioration or other conditions warranting closer monitoring are to be inspected more frequently. Certain types of structures in very good condition may receive an exemption from the 2-year inspection cycle. These structures may be inspected once every 4 years. Qualification for this extended inspection cycle is reevaluated depending on the conditions of the bridge.

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[*] ASCE, founded in 1852, is the country's oldest national civil engineering organization. It represents more than 140,000 civil engineers in private practice, government, industry, and academia who are dedicated to the advancement of the science and profession of civil engineering. ASCE is a 501(c) (3) non-profit educational and professional society.

Approximately 83 percent of bridges are inspected once every 2 years, 12 percent are inspected annually, and 5 percent are inspected on a 4-year cycle.

Information is collected documenting the conditions and composition of the structures. Baseline composition information is collected describing the functional characteristics, descriptions and location information, geometric data, ownership and maintenance responsibilities, and other information. This information permits characterization of the system of bridges on a national level and permits classification of the bridges. Safety, the primary purpose of the program, is ensured through periodic hands-on inspections and ratings of the primary components of the bridge, such as the deck, superstructure, and substructure. This classification and condition information is maintained in the National Bridge Inventory (NBI) database maintained by FHWA. This database represents the most comprehensive source of information on bridges throughout the United States.

Two documents, the American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Condition Evaluation of Bridges* and the Federal Highway Administration's (FHWA) *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, provide guidelines for rating and documenting the condition and general attributes of bridges and define the scope of bridge inspections. Standard condition evaluations are documented for individual bridge components as well as ratings for the functional aspects of the bridge. These ratings are weighted and combined into an overall Sufficiency Rating for the bridge on a 0-100 scale. These ratings can be used to make general observations on the condition of a bridge or an inventory of bridges.

The factors considered in determining a sufficiency rating are: S1- Structural Adequacy and Safety (55% maximum), S2- Serviceability and Functional Obsolescence (30% maximum), S3- Essentiality for Public Use (15% maximum), and S4- Special Reductions (detour length, traffic safety features, and structure type--13% maximum).

In addition to the sufficiency rating, these documents provide the following criteria to define a bridge as structurally deficient or functionally obsolete, which triggers the need for remedial action.

Structurally Deficient – A structurally deficient (SD) bridge may be restricted to light vehicles because of its deteriorated structural components. While not necessarily unsafe, these bridges must have limits for speed and weight, and are approaching the condition where replacement or rehabilitation will be necessary. A bridge is structurally deficient if its deck, superstructure, or substructure is rated less than or equal to 4 (poor) or if the overall structure evaluation for load capacity or waterway adequacy is less than or equal to 2 (critical). Note a bridge's structural condition is given a rating between 9 (excellent) and 0 (representing a failed condition). In a worse case scenario, a structurally deficient bridge may be closed to all traffic.

Functionally Obsolete – A bridge that is functionally obsolete (FO) is safe to carry traffic but has less than the desirable geometric conditions required by current standards. A bridge is functionally obsolete if the deck geometry, underclearances, approach roadway alignment, overall structural evaluation for load capacity, or waterway adequacy is rated less than or equal to 3 (serious). A functionally obsolete bridge has older design features and may not safely accommodate current traffic volumes, vehicle sizes, and vehicle weights. These restrictions not only contribute to traffic congestion, but also pose such major inconveniences as lengthy detours for school buses or emergency vehicles.

Structural Capacity –Components of bridges are structurally load rated at inventory and operating levels of capacity. The inventory rating level generally corresponds to the design level of stresses but reflects the present bridge and material conditions with regard to deterioration and loss of section. Load ratings based on the inventory level allow comparisons with the capacities for new structures. The inventory level results in a live load which can safely utilize an existing structure for an indefinite period of time. The operating rating level generally describes the maximum permissible live load to which the bridge may be subjected. This is intended to tie into permits for infrequent passage of overweight vehicles. Allowing unlimited numbers of vehicles to use a bridge at the operating level may shorten the life of the bridge.

Inspection Frequency
In the U.S. today, biennial inspection intervals are equally applied to the entire bridge inventory, with some exceptions, and may not be appropriate for specific bridges. For example, recently constructed bridges typically experience few problems during their first decade of service. Under the present requirements, these bridges can have the same inspection frequency as a 50 year old bridge that is reaching the end of its service life, and may face severe and rapid modes of deterioration. In the case of bridges with fracture-critical elements, elements who's failure could result in structural collapse, newer bridges with improved fabrication processes and designs intended to mitigate the effects of fatigue are inspected on the same interval as older bridges that do not share these characteristics. In many cases, these structures may not provide an equal level of risk.

A more rational approach to determining the appropriate inspection intervals for bridges would consider the design, details, materials, age and loading of specific bridges. There is a growing consensus that inspection intervals could be optimized toward meeting the goal of improving the safety and maintenance of highway bridges. A recent scanning tour of bridge evaluation quality assurance practices in Europe found that longer inspection intervals were normal, extending the inspection intervals to 6 years in some cases. However, in general these inspections were analogous to in-depth inspections in the U.S. system, in which there is an arms-reach inspection of the bridge that may include materials sampling and the application of NDE. A more detailed inspection conducted less frequently may have a positive impact on the overall safety and maintenance of bridges in the U.S., allowing for broader application of NDE technologies and a better understanding of the condition of individual bridges.

A longer inspection frequency could allow for the better utilization of resources by providing a platform for more in-depth inspections utilizing a broader array of NDE and other assessment technologies. It is worth considering the movement toward Risk-Based Inspection (RBI) for other industries. In RBI, the modes of degradation for a machine or component are identified. The probability of the degradation and the consequences of that degradation are considered in a risk assessment that is used to prioritize inspections, establish inspection intervals, and determine the scope of the inspection. In this manner, inspection efforts are focused on areas of highest risk, allowing more time and resources to be dedicated. Obviously, highway bridges present some unique challenges in terms of the variable designs employed, varying construction practices, and complex deterioration characteristics. The development of more rational, possibly risk-based inspection process should be further evaluated, and may be a suitable topic for future research and development.

Bridge Engineers and Bridge Inspectors:

Bridge inspection services should not be considered a commodity. Currently, NBIS regulations do not require bridge inspectors to be Professional Engineers, but do require individuals responsible for load rating the bridges to be Professional Engineers. ASCE believes that non-licensed bridge inspectors and technicians may be used for routine inspection procedures and records, but the pre-inspection evaluation, the actual inspection, ratings, and condition evaluations should be performed by licensed Professional Engineers experienced in bridge design and inspection. They should have the expertise to know the load paths, critical members, fatigue prone details, and past potential areas of distress in the particular type of structure being inspected. They must evaluate not only the condition of individual bridge components, but how the components fit into and affect the load paths of the entire structure. The bridge engineer may have to make immediate decisions to close a lane, close an entire bridge, or to take trucks off a bridge to protect the public safety.

III. Nondestructive Evaluation of Bridges

Nondestructive evaluation (NDE) technologies describe a class of technologies intended to characterize the condition of materials, structures or components without causing damage. Visual inspection is the most common form of NDE. More advanced NDE technologies frequently depend on the characterization of waves propagating within the materials to infer the properties of the material or detect the existence of anomalies. A familiar example to most people is a medical sonogram, which utilizes acoustic waves launched from a transducer on the surface of the skin to assess conditions within the body, for example, the existence and characteristics of a fetus in the womb of a pregnant woman. Figure 1 shows such a medical sonogram of a fetus. It is important to note that the image is an indirect measurement, in that the image is created from the characteristics of the acoustic waves, which have traveled through a portion of the body, have been reflected from the fetus and subsequently detected at the surface of the skin. It's an interpretation of these waves that a fetus exists and what size and shape it might be. Other factors, such as a knowledge that

Figure 1. Medical sonogram of a fetus in the womb.

the women is pregnant or the appearance of what could be a beating heart, contribute to the assessment that this image is of a fetus, and not of a tumor or other anomaly in the body. Other features within the body such as internal organs can obscure the image, or create an environment where misinterpretation occurs. The single fetus in Figure 1, for example, was later determined to actually be twins, the second fetus having gone undetected.

In a manner similar to a medical sonogram, acoustic waves can be utilized to detect subsurface anomalies in solid materials such as bridge members. An acoustic wave can be launched into a member and will be reflected from internal features that may exist such as a crack or embedded void, and the boundaries of the material. This wave can then be detected later in time, and analysis of the travel time, size, shape and frequency of the detected waves interpreted by trained personnel to infer if a flaw exists and if so, estimate its size and shape. However this is not a direct measurement of its size and shape, and as such there is always a role of interpretation and engineering judgment involved in assessing what factors and material characteristics have affected the properties of the detected wave, and if the indications observed represent a flaw or may be some irrelevant indication.

The technique of using acoustic waves launched into metals to detect and characterize flaws is termed Ultrasonic Testing (UT), and is employed in a broad range of industries for the nondestructive evaluation of steel members, engine components, pipelines etc. For highway bridges, it is commonly employed in the fabrication process for the quality assurance of welds. For in-service bridges, it is common practice to utilize this method for the detection of cracks in bridge pins, and to a much lesser extent for the detection of fatigue cracking. A survey published by the FHWA in 2001 indicated that 81% of States responding to the survey utilized this technique for bridge inspection. Though the extent of that use is not fully known, it is not common as part of the initial bridge inspection but rather is utilized to address a specific component such as a bridge pin, or to address a known problem area during a special inspection.

Ultrasonic testing provides a useful analogy for describing in general terms characteristics of many NDE technologies. A transducer such as shown in figure 2A is placed on the surface of the material. This transducer launches a wave that transmits into the material, and is reflected by the boundaries of the material and internal flaws, if they exist. The reflected wave itself appears on an oscilloscope screen as shown in figure 2B. The transducer is scanned over the surface of the material to search for anomalies in the received signal, known as an "indication," that may correspond to a flaw. If such a signal is found, it is analyzed to determine if the indication is likely to arise from a flaw in the material and if so, to estimate the size and shape of the flaw. The development of powerful, portable computing resources has allowed for the responses that occur during the scanning process to be integrated into a spatial image that shows specific characteristics of the wave, for example its amplitude. Such an image developed from the acoustic response of embedded flaws in a weld is shown in figure 2C, and a radiographic image of the flaws is shown in figure 2D. As the figure indicates, both radiography and ultrasonic testing has the capability of revealing subsurface flaws that are typically unavailable for visual inspection, and can assist in estimating the size, shape and location of the flaw. NDE methods such as these can provide powerful tools that increase the ability to understand the condition of structures and detect deterioration in its early stages, such that action can be taken to improve the safety and maintenance of bridges.

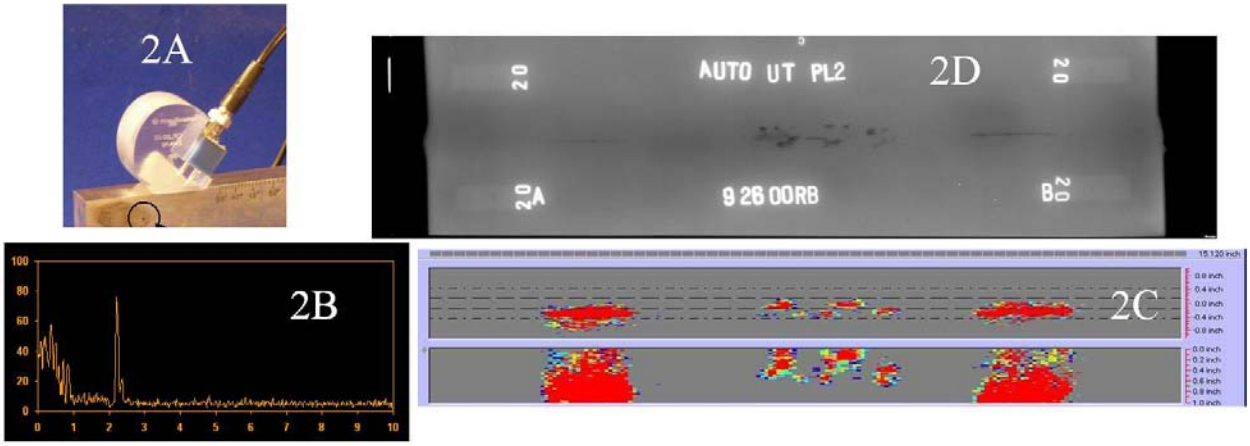

Figure 2. NDE data from ultrasonic and radiographic testing. 1A shows a typical ultrasonic transducer; 1B shows a reflection from subsurface flaws; 2C is an image developed from ultrasonic test results; 1D is a radiograph of flaws in a weld . (*FHWA Turner Fairbank Highway Research Center*)

The use of wave phenomena for nondestructive evaluation can be sorted into two general categories; those involving the interpretation of electromagnetic waves and those involving the interpretation of acoustic waves. Generally, these methods utilize the characteristics of wave propagating within or from a material under test to interpret if a flaw exists, or in some cases, to characterize strength-related properties of the material. A third class of related technologies, such as using strain gages to evaluate structural behavior, are in general health monitoring techniques, which may or may not include nondestructive evaluation technologies as elements of the overall systems.

Electromagnetic wave methods include such technologies as ground penetrating radar (GPR), which launches a high-frequency electromagnetic wave into a concrete structures and interprets reflections from internal features, such as delaminated concrete, in a manner analogous to ultrasonic testing. This method has shown to be useful for estimating the areas of concrete deck that may require maintenance or repair, though results have been variable. Other EM methods include radiography, eddy current testing, magnetic particle testing, microwaves, infrared thermography and others.

Acoustic wave methods include a broad variety of technique for the nondestructive evaluation of steel and concrete. Techniques that would fall generally in this category include ultrasonic testing, acoustic emissions, impact echo, impact velocity, vibration testing, chain drag and sounding, among others.

NDE Technologies

The following section lists a few of the NDE methods available for the condition assessment of highway bridges. Further descriptions of these methods can be found in Appendix A. The methods discussed are primarily those applied for superstructures and decks for the condition assessment of existing structures. Additional NDE technologies that may play a role in the quality assurance of construction practices have been omitted, although some of the techniques discussed are also used in that manner. The methods described are some of those widely available commercially, and it should be noted that a number of variations of the general techniques exist. First, NDE technologies for concrete are discussed, followed by NDE technologies of steel. A final section describes the use of nondestructive load rating of structures and health monitoring.

Concrete

Concrete is a heterogeneous material consisting of cement paste, aggregates and embedded reinforcing steel. The primary deterioration modes for this material are driven by the environment, with corrosion of the reinforcing steel and resulting delaminations and spalling being a widespread issue in superstructures, substructures and decks. A number of NDE tools are available for assessing the condition of concrete bridge components. Methods for the detection of subsurface deterioration include:

- Sounding
- Impact Echo
- Ground penetrating radar (GPR)
- Infrared Thermography

Methods for detecting subsurface voids and other defects include:

- Radiography
- Ultrasonic Pulse Velocity
- Impact Echo

There are also a number of tools and instruments that can be used to determine if corrosion is occurring in the embedded reinforcing steel, including half-cell potential measurements, among others.

Steel Bridges

NDE technologies for steel bridges are focused largely on the detection of flaws, usually fatigue cracks, that may develop as a result of in-service loading. Methods vary in that some methods allow only for the detection of flaws, and are limited in their ability to measure fully the extent of the flaw. These methods generally allow for the detection of flaws that are surface-breaking and in areas available for visual observation. These methods include:

- Dye Penetrant
- Magnetic Particle
- Eddy Current

The ultrasonic testing method described previously has the advantage of being capable of extending its use to areas that may be hidden from view, and flaws do not need to be surface-breaking to be detected. This technology may also be used to quantify the effects of corrosion. Acoustic emissions testing can also be employed on steel bridges to detect and/or monitor fatigue cracking. Radiography can also be employed for detecting flaws in steel bridges, though it is primarily used during fabrication of bridges due to operational constraints.

Nondestructive Load Rating and Health Monitoring

Nondestructive load rating describes a process for determining the field performance of a bridge through a series of controlled tests that measure bridge response to applied loads. This approach may be used to define a limit load for a bridge, to confirm load ratings, or to better define structural behavior. The method generally involves applying sensors such as strain gages and deflection sensors to a bridge, and then loading the bridge with known loads and evaluating response. Analytical modeling of bridge behavior is generally a component of this process.

Health monitoring of bridges can be generally defined as monitoring bridge behavior over time. Sensors such as strain gages, tilt meters, accelerometers, and variable differential transformers are among those used for this purpose. There are a number of systems that can be used to monitor the bridge to provide real time data and alert the owner of such things as failure of a load carrying member, excessive rotation or displacement of an element, overload in a member or scour around a bridge pier. The type of information provided is typically very specific and provides data on isolated areas or members of the bridge. Monitoring systems routinely need to be verified and maintained, and typically do not eliminate the need for inspections since only isolated areas are examined. Health monitoring systems that are global in nature have been developed on an experimental basis, but there value within the context of bridge management and condition assessment has yet to be proven.

Role of NDE in Bridge Inspections

The role of NDE technologies beyond visual inspection has traditionally been limited in terms of the routine inspections of highway bridges, that is, the inspections that meet the minimum federal requirement. This is due in part to the reality that the data required to complete an NBIS-type inspection does not require NDE beyond visual inspection. However, that does not mean that NDE technologies are not used for the condition evaluation of bridges by State Departments of Transportation, which themselves have responsibility for the maintenance and operation of highway bridges. The use of sounding, for example, is widespread as a method to identify areas of deteriorated concrete and subsurface flaws, and is frequently part of a routine inspection.

It should be explained that the role of NDE in bridge inspection, and bridge inspections themselves, extend beyond ensuring the safety of bridges. The collection of data on the condition of bridges is an important component to their maintenance. NDE can play an important part of detecting deterioration in its embryonic stages, when remedial measures and repair can extend the useful life of a bridge and reduce the cost of future repair and rehabilitation. This may be well in advance of the deterioration progressing to a point where safety is a concern. Therefore, these technologies should be considered not only in terms of ensuring bridge safety, but also in terms of improving the process of bridge maintenance and management.

In terms of ensuring bridge safety, a number of NDE techniques can and do play a role in the inspection process. Using cracking in steel bridge members as an example, there are a number of technologies available with the capability to detect cracks in steel; a few have been described above. Ultrasonic testing has been discussed previously that uses acoustic waves to detect subsurface flaws. Other methods that are available to detect cracks include dye penetrant and magnetic particle. These two methods are well proven both for bridge inspection and in other industries. The advantage of these methods are that they are simple, there is widely available training and resources, and they can be highly portable. The primary disadvantages include that they are time consuming, very local in nature, highly inspector dependent, and require close access to the surface being tested.

More advanced methods for detecting cracks in steel include ultrasonic testing as previously discussed, and eddy current testing. Advantages of ultrasonic testing include that it has the capability to reveal subsurface flaws, it can be used to investigate areas that are not available for visual inspection, and has increasing capabilities to produce spatial images of results that can aide in the interpretation of the data. This technique also has widely available training and resources, though training requirements are typically significantly greater than in the case of dye penetrant or magnetic particle, due to the complexity of the method.

All of these methods for detecting cracks in steel bridges face a similar and significant challenge. Although they have the capability to detect cracks beyond the capability of visual inspection, they are extremely time consuming and costly to employ on a wide-scale basis in the field. Using ultrasonic testing as an example, to detect flaws as shown in figure 1 requires detailed scanning over the area where a flaw is anticipated, and may require significant surface preparation, and interpretation of results can be complex. The transducers utilized for conducting this testing are typically on the order of 1 in. square. Scanning a bridge, which may be 2 thousand feet long and contain hundreds of potentially problematic details, can be operationally impractical. Even if the areas requiring scanning can be reduced through engineering knowledge and experience, the technique still requires a high level of access to the surface of the structure that may not be readily achievable. Further, the results of the testing are an indirect measurement, and as such rely heavily on the interpretation that can be highly complex. The occurrence of “false positives,” that is flaws reported where none exist, can undermine confidence in the method.

A significant challenge to the application of NDE technologies for highway bridges is providing reliable, quantitative results under a variety of experimental conditions. Although the capability to detect certain types of defects or flaws may exist, the reliability of that process under real-world conditions must be established. This has proven difficult in a number of cases due to the challenging environment experienced during bridge inspections. Widely varying materials, designs and construction practices may lead to uncertainty in the results of NDE inspections. Because NDE technologies are in general indirect measurements, and sensitive to a variety of factors other than the specific flaw they are intended to characterize, results can often be uncertain and qualitative. Additionally, a variety of deterioration modes, mostly driven by the environment, may occur simultaneously and undermine efforts to detect certain flaws for which a method is intended. For example, cracking in steel may occur at the same location as severe corrosion, making the detection of cracking much more complex. A broader understanding is required of the complexity of bridge inspections and the application of NDE technologies as a part of those inspections.

An additional complication with NDE technologies in general is that these technologies are intended to detect and characterize flaws or material condition. The significance of a detected flaw requires engineering analysis to determine if the flaw has a detrimental impact of the behavior or durability of the structure, and if so, to also determine the appropriate remediation. This process is complicated if the NDE results include significant uncertainties.

It should be noted that despite these challenges, the role of NDE technologies in bridge inspection has been growing. Methods such as ultrasonic testing of bridge pins are in widespread use, as are magnetic particles testing, dye penetrant, impact echo and pulse velocity measurements, to name a few. These methods are frequently employed in the context of special inspections, where visual inspections have identified potentially problematic areas in need of additional analysis and testing. Other methods, such as GPR, have found a role in evaluating bridge conditions on a system level, to qualitatively determine bridge decks in relatively better or worse conditions. New instrumentation for the nondestructive load rating of bridges, such as wireless sensors and laser measurement devices, has improved accessibility of these techniques and contributed to increased application. Continued efforts to develop and apply these innovative technologies is an important component of ensuring the long term safety and reliability of the nation's bridges and other infrastructure.

Research Needs
A primary challenge to the application of NDE technologies for the inspection of highway bridges is developing effective methods for implementation. Although these technologies may have the capability to detect certain flaws or anomalies, the reliability of the techniques to provide accurate, conclusive results remains a significant limitation in many cases. Research is required to establish which methods can provide data that is reliable, and produces results significantly beyond what could be accomplished with visual inspections such that the increased cost (beyond the cost of visual inspection) is justified. To date, this remains an elusive goal for many NDE technologies. Additionally, methodologies that will allow these technologies to be effectively applied within the context of bridge inspections, with consideration for the unique challenges associated with the environment and access limitation of bridges, are needed. The widely varying nature of materials, designs and construction make quantitative definition of the reliability of NDE techniques particularly complex for highway bridges. Investment in addressing reliability issues with NDE technologies, such as quantitative analysis of detection probabilities, could improve and broaden their application.

An important gap in research presently is effective methods for the condition assessment of prestressed and post-tensioned bridges. For these structures, prestressing strands or tendons that play a critical role in structural performance are embedded in concrete, such that they are unavailable for visual inspection. These tendons are highly susceptible to the effects of corrosion, and tendon failures have been experienced in the field. It should be noted that the construction of bridges with these design features began on a widespread basis in the 1960's, such that this population of bridges is just now reaching 50 years of age. New bridge designs, such as cable-stayed bridges, also utilize these strands within the main stays, sometimes embedded within a cementitous grout intended to provide corrosion protection. The resulting configuration presents limited access for inspection and evaluation of these critical components. The lack of effective methods for assessing the condition of the embedded steel is a significant gap in available technologies. The critical need for research and development to address this gap is urgent.

Education and Training
It should be recognized that a significant barrier to the effective development, application and implementation of NDE technologies is a lack of suitable education and training. These technologies typically require knowledge that is multi-disciplinary in nature, combining concepts and practices from physics, electrical engineering, mechanical engineering and materials science, among others. Typical training for Civil Engineers, in fact, engineers of any discipline, does not adequately address these topics in an integrated fashion as they are applied NDE technologies. Such education at the undergraduate and graduate level is needed to develop a foundation of

knowledge to support critical thinking and analysis, and develop engineers with adequate knowledge to effectively apply NDE technologies. Presently, the application and limitations of NDE technologies remains outside the expertise of the engineers that may rely on the technologies for critical decision making in the future.

Training in the use and application of NDE technologies as a part of undergraduate education for Civil Engineers is very rare. Likewise, durability and maintenance of structures is not a common topic for undergraduate education. Even though corrosion and its effects represent perhaps the most significant challenge to health of our infrastructure, study of corrosion science is essentially unknown in undergraduate civil engineering curriculum. Additional focus on training and education of the engineering community, such that a deeper understanding of the potential and limitations of NDE technologies is developed, should be explored. Increased education focused on the important areas of maintenance and preservation of infrastructure should also be considered key for developing engineering expertise and depth on a national level, and addressing the critical needs for maintaining the ageing infrastructure.

IV. ASCE's Public Policy Statements Regarding Bridges

Funding programs for transportation systems, i.e., federal aviation, highways, harbors, inland waterways, and mass transit as documented by the U.S. Department of Transportation, need to be increased, to provide orderly, predictable, and sufficient allocations to meet current and future demand. The Highway Trust Fund is in danger of insolvency (as other trust funds may be in the future) and must receive an immediate boost in revenue to ensure success of multi-modal transportation programs. In fact, the Office of Management and Budget estimates that in FY 2009 the Highway Account of the Highway Trust Fund will be in the red by as much as $4.3 billion.

The safety, functionality, and structural adequacy of bridges are key components necessary to support and ensure the safe, reliable, and efficient operation of transportation infrastructure and systems which provide mobility of people and the movement of goods and services. Federal policy establishes the minimum bridge safety program components necessary for both public and private bridges to ensure an adequate and economical program for the inspection, evaluation, maintenance, rehabilitation, and replacement of our nation's bridges.

Continued neglect and lack of adequate maintenance will ultimately result in higher annual life-cycle costs of bridges due to shortened service life. Therefore, investment to improve the condition and functionality of the nation's bridges will reduce the required investment in the future.

Bridge Safety
For the continued safety of the nation's bridges, ASCE advocates that a bridge safety program for both public and private bridges be established, fully funded, and consistently operated to upgrade or replace deficient bridges and to properly maintain all others. This program should preserve full functionality of all bridges to support the operation of safe, reliable and efficient transportation systems, and to allow these systems to be utilized to their full capacity. Such programs should include as a minimum:

- Regular programs of inspection and evaluation that incorporate state-of-the-art investigative and analytical techniques, especially of older bridges which were not designed and constructed to current design loading and geometric standards;
- Posting of weight and speed limits on deficient structures;
- Implementing and adequately funding regular system-wide maintenance programs that are the most cost-effective means of ensuring the safety and adequacy of existing bridges;
- Establishing a comprehensive program for prioritizing and adequately funding the replacement of functionally obsolete and structurally deficient bridges;
- Setting a national goal that fewer than 15% of the nation's bridges be classified as structurally deficient or functionally obsolete by 2010

Transportation Funding

Adequate revenues must be collected and allocated to maintain and improve the nation's transportation systems and to be consistent with the nation's environmental and energy conservation goals. A sustained source of revenue is essential to achieve these goals.

ASCE recommends that funding for transportation system improvements, associated operations, and maintenance be provided by a comprehensive program including:

- User fees such as motor fuel sales tax;
- User fee indexing to the Consumer Price Index (CPI);
- Appropriations from general treasury funds, issuance of revenue bonds, and tax- exempt financing at state and local levels;
- Trust funds or alternative reliable funding sources established at the local, state, and regional levels, including use of sales tax, impact fees, vehicle registration fees, toll revenues, and mileage-based user fees developed to augment allocations from federal trust funds, general treasuries funds, and bonds;
- Refinement of the federal budget process to establish a separate capital budget mechanism, similar to many state budgets, to separate long-term investment decisions from day-to-day operational costs;
- Public-private partnerships, state infrastructure banks, bonding, and other innovative financing mechanisms as appropriate for the leveraging of available transportation program dollars, but not in excess of, or as a means to supplant user fee increases;
- The maintenance of budgetary firewalls to eliminate the diversion of user revenues for non-transportation purposes, and continuing strong effort to reduce fuel tax evasion.

V. Conclusion

This testimony has attempted to provide some explanation of what NDE technologies are, and how they are applied within the context of highway bridge inspections. Limitations associated with the complex nature of bridges and their deterioration has been described. There exist tremendous potential to improve bridge safety and maintenance through the proper application and use of NDE technologies. However, there are limitations, many related to the ability of NDE methods to provide quantitative results that clearly provide improvements over the capabilities of visual inspection. There exist tremendous potential for NDE technologies to address the most significant inspection challenges faced in the long-term management of our nation’s bridges, and additional research and development is critical to realizing that potential.

Several specific areas of research have been described as well as the important need to provide additional training and education in this unique area.

Successfully and efficiently addressing the nation's infrastructure issues, bridges and highways included, will require a long-term, comprehensive nationwide strategy—including identifying potential financing methods and investment requirements. For the safety and security of our families, and our nation, we can no longer afford to ignore this growing problem. We must demand leadership from our elected officials, because without action, aging infrastructure represents a growing threat to public health, safety, and welfare, as well as to the economic well-being of our nation.

Thank you, Mr. Chairman. That concludes my statement. I would be pleased to answer any questions that you may have.

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Appendix A – NDE Technologies for Highway Bridges

The following section describes few of the NDE methods available for the condition assessment of highway bridges. The methods discussed are primarily those applied for superstructures and decks for the condition assessment of existing structures. Additional NDE technologies that may play a role in the quality assurance of construction practices have been omitted, although some of the techniques discussed are also used in that manner. The methods described are some of those widely available commercially, it should be noted that a number of variations of the general techniques exist. First, NDE technologies for concrete are discussed, followed by NDE technologies of steel. This is not intended to be a comprehensive list, but a sampling of some of the more common NDE technologies.

Sounding

This method consists of striking the surface of the concrete with a hammer and listening for tones that indicate deteriorated concrete. In many cases, this method is implemented using a series of chains dragged over the surface to achieve the same effect. In either case, this method has proven an invaluable tool to inspector for determining the extent of subsurface deterioration, which may not be visually observable. The application of this technique is widespread, due in part to its simplicity and low cost. The results of sounding may play a role in the inspector rating of a bridge component, contributing to the overall understanding of its condition.

Half – Cell Potential

This method consist of measuring the corrosion potential of embedded reinforcing steel to infer if active areas of corrosion are present. This method is widely available from consulting firms and within State Departments of Transportation, applied primarily to identify active corrosion in bridge decks.

Pulse-Velocity

Measuring the velocity of a pulse of ultrasonic energy (wave) propagating within concrete can be used to determine empirically the elastic properties of the material. This method is generally used to define the extent of damage in concrete, and is sometimes used to identify subsurface voids. A significant disadvantage faced in the application of this technique is that it generally requires access to two sides of the material under tests, limiting its practical application to cases where such access is achievable.

Impact-echo

The impact echo method is closely related in physics to the pulse velocity and sounding. The method is normally performed by impacting the surface of the concrete, and measuring the response to that impact with accelerometers or other suitable instrumentation.

The wave characteristics of the response, such as frequency and velocity, are interpreted to determine the thickness of a concrete deck, subsurface deterioration, or internal voids. A multitude of variations that generally fit this description have been developed that examine and interpret the response in different ways. An advantage to these techniques over the pulse-velocity approach is that they typically require access to only one surface of the material under test. Disadvantages include that the application of the techniques can be time consuming, and results can at times be inconclusive.

Ground Penetrating Radar (GPR)
GPR launches a high-frequency electromagnetic wave into a concrete structure and interprets reflections from internal features, such as delaminated concrete. This method has shown to be useful for estimating the areas of concrete deck that may require maintenance or repair, though results have been variable. This method is also useful for determining the locations of embedded metallic materials, such as reinforcing bars or ducts in post-tensioned bridges. A significant advantage to this approach is that GPR can be implemented from air-launched antennas, which allow for inspections of concrete decks to be conducted at highway speeds in some cases. A disadvantage of the method is that results can rely heavily on expert interpretation.

Infrared Thermography
Infrared thermography is method of analyzing the thermal transfer properties of a material. In concrete, for example, subsurface anomalies such as delaminations effect the rate of heat transfer through the material, which manifests as variations in the surface temperature resulting from diurnal temperature variations. An infrared camera can be used to develop an image of the surface of the material by measuring the rate at which electromagnetic energy is emitted from the material, which is highly sensitive to the temperature of the material. Figure 2 provides an example of an infrared image. In this image, subsurface targets embedded in concrete at depths of 1, 2, 3 and 5 inches are imaged using an infrared camera. The advantage of this technique is that it can be applied from some distance, such that direct access to the structure is not required. A primary value of this is the lack of traffic disruption that may be required to implement the technique. A significant disadvantage is that the method depends entirely on environmental conditions to function. The appropriate environmental conditions for conducting effective inspections is the topic of current research.

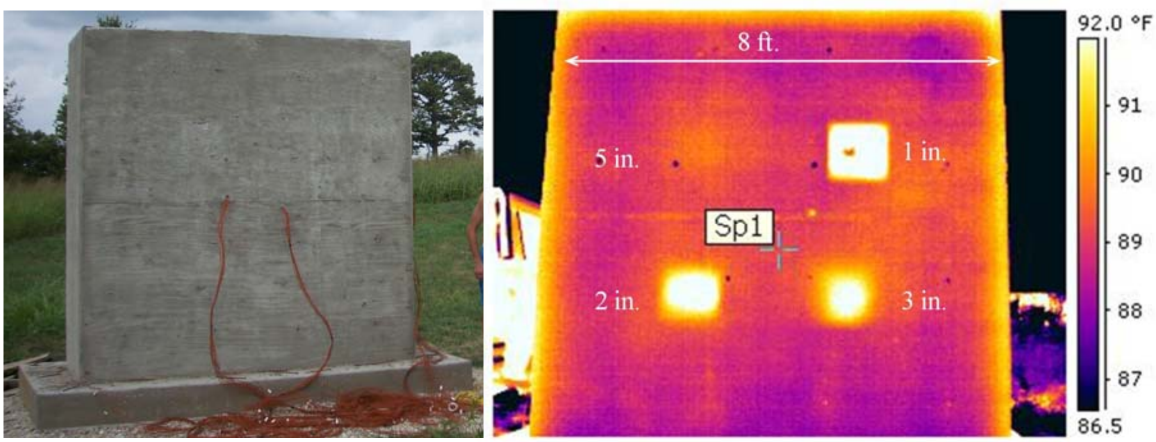

Figure 2. Infrared image of a 8 ft. x 8 ft. concrete block (shown on left) with targets embedded in concrete at depths of 1, 2, 3 and 5 inches. *(University of Missouri – Columbia)*

Radiography
Like a medical x-rays, images of the internals features in concrete bridges can be developed using linear accelerators or even isotopes in certain circumstances. The ability to penetrate significant thickness of concrete make this a viable technique for the detection of certain internal flaws, such as grout voids in post-tensioning ducts. Like a medical x-ray, photons radiating from

a tube or isotope are directed through a material and detected by a film or digital detector. The photons carry the legacy of the materials through which they have traveled. The photons are scattered more by highly dense materials then by materials of lower density. The resulting image is a two-dimensional map of the density variations in the materials under test. Density variations that result from flaws in the materials appear in the image and can be interpreted by a trained inspector. It should be noted that this technique can and is used for steel bridges as well as concrete bridges. Highly specialized training and safety procedures are required for implementation, making this method difficult and costly to apply in the field.

Steel Bridges
There are a multitude of NDE technologies available for steel bridges, primarily focused on the detection and characterization of cracks in steel. Most of the techniques available have been developed initially for other industries, such as manufacturing and aerospace. A few of the most widely available and utilized methods are described here.

Dye Penetrant
Dye penetrant is a relatively simple technique in which a dye applied to the surface of the steel is used to reveal the existence of a crack that may not be apparent to the naked eye. A developer is typically used to improve the contrast between the dye emerging from a crack and the surrounding area. While simple to use, the method is time consuming and requires extensive surface cleaning to be effective.

Magnetic Particle
Magnetic particle testing induces a magnetic field in the steel, and finely divided iron particles applied to the surface are attracted to field leaking from a crack. This method is widely applied in the fabrication of steel bridges, and can also be used in the field.

Ultrasonic Testing
Ultrasonic testing has been previously described, the method generally launches an acoustic wave into the steel, and reflection from internal features create reflections that are detected and subsequently analyzed.

Eddy Current
The eddy current method detects cracks by the monitoring the effects of a crack on the trajectories of induced electrical currents in the surface of the steel. The interpretation of results, however, can be complicated and operator dependant, especially in the bridge environment, where nonrelevant indications due to geometric effects are prevalent. The advantages of this technique include the ability to detect cracks beneath coatings, highly portable equipment and minimum surface preparation. New approaches to applying this technique include the ability to produce spatial images of results, which may support improved detection and evaluation capability. Several variations of this basic method are available.

Acoustic Emission Testing
Acoustic emission systems are intended to detect and monitor the energy released as a result of crack growth. The method is typically implemented by placing sensors at or near a location

where a crack is anticipated or known to exist, and monitoring for small acoustic waves released during crack growth. This method has been demonstrated to be effective for monitoring known cracks in steel bridges in some cases. In recent years, systems that monitor cables such as those in a cable-stayed bridges have been developed. These systems detected the sound energy released by a wire break, and several systems have been installed on major bridges in the US to monitor the rate of wire fractures.